Spectral Wave Decay Due to Bottom Friction on the Inner Shelf

Timothy P. Stanton
Oceanography Department
Naval Postgraduate School
Monterey, CA 93943-5000
phone: (831) 656 3144 fax: (831) 656 2712 email: stanton@oc.nps.navy.mil

Edward B. Thornton
phone: (831) 656 2847 fax: (831) 656 2712 email: thornton@oc.nps.navy.mil

Award#s: N0001401WR20034; N0001401WR20032; N0001401WR20373
http://www.oc.nps.navy.mil/~stanton/showex/

LONG TERM GOALS

Long term goals are to observe and model wave and current boundary layer processes to determine wave dissipation and wave-bed interactions in coastal and nearshore regions using novel instrumentation techniques.

OBJECTIVES

The primary scientific objective of this project is to measure the bottom dissipation of surface gravity waves as they shoal across the continental shelf as a component of the Shoaling Waves Experiment, SHOWEX. Detailed observations of the bottom boundary layer (BBL), resolving the thin oscillatory wave boundary layer over a rippled sandy bed, have been made at two sites with differing wave forcing, mean currents and sediment bed types, to develop a spectral wave dissipation model for the continental shelf. At each site, continuous maps of the small-scale morphology have been made in an area surrounding the detailed bottom boundary layer measurements to study changes in the bed in response to wave forcing, and to relate the effects of these morphology changes on turbulence in the BBL. A spectral dissipation model is being developed to include effects of a wave-forced mobile bed, and parameterizations for low frequency currents including strong baroclinic tidal and wind-driven currents.

APPROACH

During 1999, two long term inner shelf observation sites were established to measure wave and current forcing and detailed measurements of BBL - bed responses. The Monterey Inner Shelf Observatory (MISO, Stanton 1999) has a shore-cabled instrument frame at 12m depth in the southern end of Monterey Bay at a site with .15mm mean diameter sandy bed and moderate, primarily narrow band, long period swell forcing conditions. A second site was established in 11m of water offshore from the Duck pier between 28 September and 10 December 1999 during the main SHOWEX observation program. The Duck site has significantly finer sediment and forcing is generally shorter period, with frequent energetic wave forcing, and strong, low frequency, alongshore currents in comparison with the Monterey site. A year-long wave forcing and bed map timeseries at the Monterey Bay site has been

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Spectral Wave Decay Due to Bottom Friction on the Inner Shelf**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Oceanography Department,,Naval Postgraduate School,,Monterey,,CA, 93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Long term goals are to observe and model wave and current boundary layer processes to determine wave dissipation and wave-bed interactions in coastal and nearshore regions using novel instrumentation techniques.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

completed, providing a unique data set to test ripple formation models over a wide range of seasonal wave forcing conditions.

At each field site, dissipation rates in the bottom boundary layer have been estimated from O(1cm) resolution, three component velocity profiles measured by a Bistatic Coherent Doppler Velocity Profiler (BCDVP) instrument (Stanton 1996, 2001a,b). These instruments measure vertical profiles of velocity and sediment concentration over a 60 cm range above the bed at a 20Hz rate. These small-scale measurements of the bottom boundary layer are extended through the water column with high speed Broad Band Acoustic Doppler Profilers. Wave dissipation rates in the mean current and wave-forced bottom boundary layer are being estimated by decomposing mean, wave, and turbulent components of the three component velocity vector profiles to estimate the wave work term that dissipates wave energy in the WBBL. The co-located measurements of the velocity vector profiles and sediment concentration also allow the sediment buoyancy terms in the TKE balance in the bottom boundary to be estimated when sediment suspension is occurring.

As the local sediment morphology can greatly influence the characteristics of the bottom boundary layer, a two axis scanning sonar altimeter was developed and deployed to quantitatively measure finescale morphology over a 2 by 2 m area spanning an area below the BCDV profile measurements, with 2cm horizontal and 0.25 cm vertical resolutions and 10-15 minute sampling. These local morphology maps were extended at the Duck site by qualitative 2D side-scan morphology images out to a 10m radius around the instrument frame to identify larger scale morphological features. In addition, cross-shelf side-scan swaths of larger scale bed features were measured with a mulitbeam survey sonar from the R/V Creed in collaboration with Fred Dobson to estimate mobile bed changes to strong forcing events.

Three modeling efforts are in progress to test morphology evolution and wave dissipation parameterizations. A full DNS model developed by Don Slinn simulates turbulent flow over a sinusoidal bumpy bed. The model is being run at NPS with laboratory scale waves, and the scaled velocity fields have been resampled in time and space with a modeled BCDVP response to assess the robustness of the stress, shear and shear production method used estimate wave dissipation rates in the oscillatory boundary layer. The DUNE2D boundary layer model for small-scale morphology, (Andersen, 1999), has been used by a graduate student, LCDR Steve Martin, to model bedform evolution at the Duck site. The model consists of inter-linked modules for flow, sediment transport and morphology. The flow module is based on solving the Navier-Stokes equations in the vertical plane with k-epsilon turbulence closure. This 2D model is significantly less expensive than the DNS to run on ocean-scale 2D domains, and is being used to test simple morphology formation models using forcing and mapped morphology from the Duck site. The objectives in our modeling efforts are to test and improve on existing ripple formation models based on spectral wave forcing and prescribed mean currents, and to compare predicted wave stress and wave work rates with the SHOWEX observation timeseries. The BBL dissipation formulations will be tested against *in situ* cross shelf directional wave buoy observations being made by Herbers and O'Rielly at the SHOWEX site, and incorporated into a shelf wave model being developed by Phd student Fabrice Arduin and Tom Herbers (Arduin et al, 2000).

WORK COMPLETED

Analysis of data from prototype versions of the BCDV and scanning altimeter used during SandyDuck and the SHOWEX observations have allowed techniques to be developed for estimating Reynolds stresses and dissipation rate profiles across the thin oscillatory boundary layer above a sloping and rippled bed. Part of this work has been accomplished with theoretical contributions from NICOP collaborators Paolo Blondeux and Geovana Vittori. (Blondeaux et al 1999 and 2000).

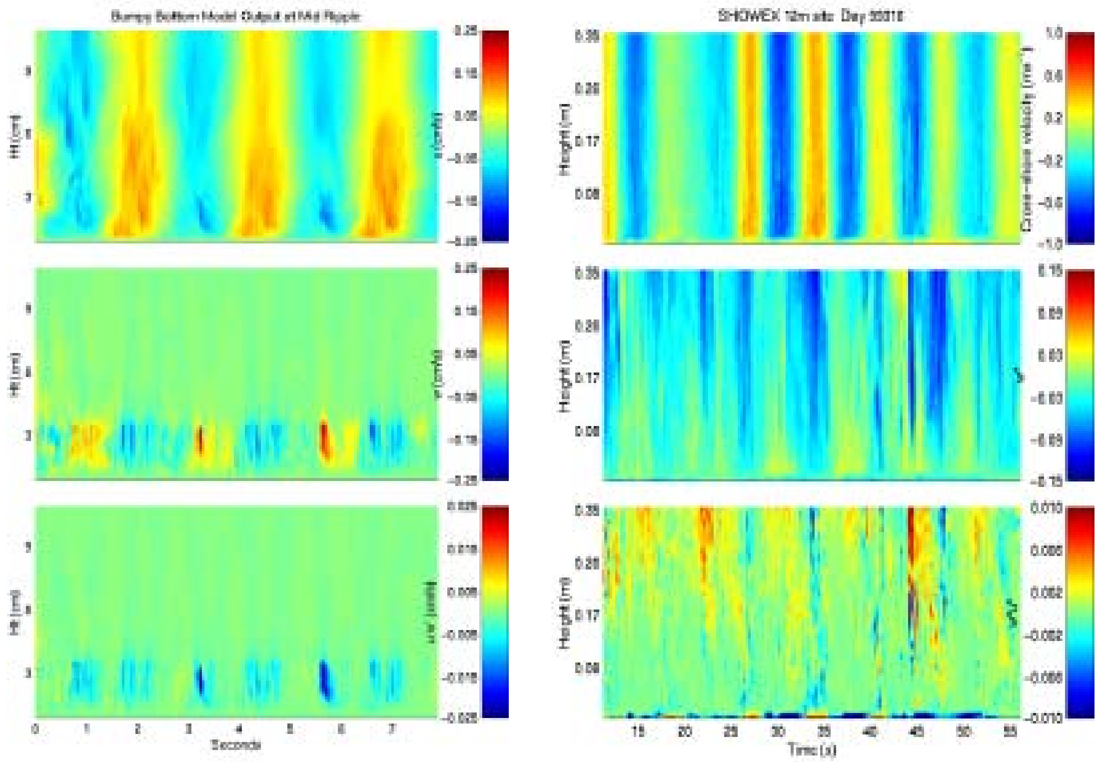
Results from Direct Numerical Simulations of a randomly forced oscillatory bottom boundary layer developed by SHOWEX collaborator Donn Slinn are being used to explore how the finite sample volume, vertical profiles of velocity made by the BCDV can be optimally used to measure the wave dissipation rates. High resolution model output from both a flat bottom run and a sinusoidal rippled bed have been “sampled” using the acoustic response of the BCDV to investigate what part of the stress and strain and shear field is resolved by the instrument, and importantly, what turbulence terms contributing to dissipation are not resolved. These detailed simulations suggest that the limited resolution oscillatory boundary layer measurements made with the BCDV adequately resolve the dominant wave-induced shear production terms across the oscillatory boundary layer for bed morphologies observed both at Duck and Monterey Bay

A processing technique has been developed to analyze the long time series of bed morphology maps made by the X/Y altimeter. The processing extracts dominant ripple direction, crest lengths, ripple height and wavelength statistics from each map. A MS thesis project is in progress to perform a statistical anaylsis of the bed response to selected wave and current forcing parameters for the Monterey Bay MISO timeseries. A similar analysis has been completed fro the Duck SHOWEX site, and a manuscript describing the bed response and comparison with exiting laboratory-based models is in progress.

RESULTS

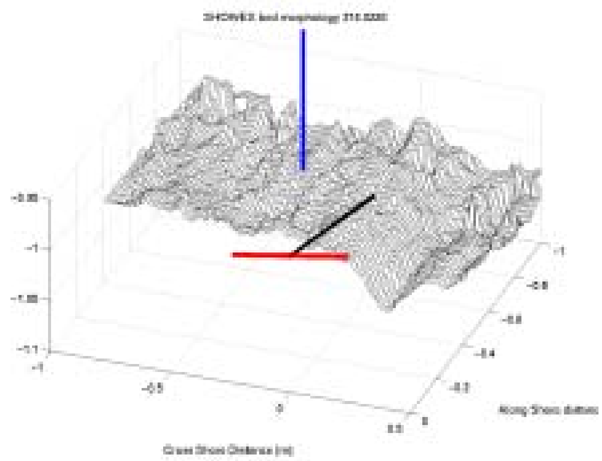
Analysis of the 0.6cm resolution vertical profiles of three component velocity measured by the BCDV have allowed the near-bed vertical Reynold’s stress profiles to be estimated while minimizing the contributions of the strong wave-induced oscillatory flow to the cross-shore $\langle v'w' \rangle$ correlations. Under moderate to strong wave conditions, the stress profile is resolved across the 4 to 10cm thick oscillatory boundary layer allowing a τ_{0w} wave bed stress to be estimated. The resulting wave work rate compares favorably to the integrated wave shear production term estimated across the oscillatory boundary layer. Stanton 2001a describes the BCDV instrument and it’s application to measuring turbulent stresses and dissipation in the wave bottom boundary layer.

An example of streamwise and vertical velocity component profiles above a sinusoidal bed from a Direct Numerical Simulation (DNS) is shown in Figure 1a. The model code, which solves Navier Stokes equations without turbulence closure parameterizations down to molecular viscous scales, was developed by Don Slinn and Tom Pierro at the University of Florida. It was run at NPS with a laboratory scale 10cm streamwise, 2.5cm cross-stream by 10cm high domain, a 20cm sinusoidal 20 cms^{-1} amplitude forcing at the top level, and a 1.8cm amplitde stream-wise ripple.

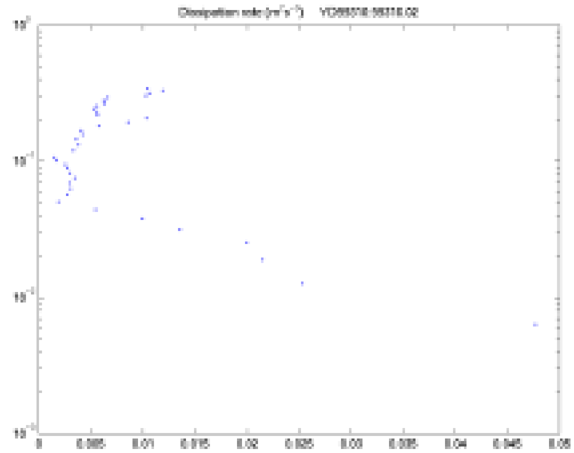


a b

Figure 1a. An 8 second timeseries of steamwise velocity (upper panel), vertical velocity (middle panel) and turbulent correlation u'w'(z,t) (lower panel) for a DNS simulation of laboratory-scale waves over a sinusoidal rippled bed, sampled half wave up the ripple. 1b, right panel. A 60 second profile timeseries of cross-shore velocity (upper panel), vertical velocity (middle panel) and turbulent correlation u'w'(z,t) sampled at the location of the blue profile line in figure 2a. A Reynolds average of ρ<u'w'> represents the turbulent stress at each measurment bin above the bed. These observations were made with the BCDVSP at 12m depth during a developing storm on yearday 316 during the SHOWEX. The mean orbital displacement was 0.9m dominated by groupy 8 second swells.



a



b

Figure2a. A mesh grid map of the bed morphology during the observations shown in figure 1b. The z axis is an arbitary displacement below the scanned altimeter used to map the bed. The vertical blue line represents the position of the BCDVPS velocity profile, while the red vector represents the principal axis of the velocity outside the wave boundary layer, and the black vector (to the same scale) is the mean current direction. Sediment suspension was occurring during the stronger cycles of the wave groups. Figure 2b. A semilog axis plot of the shear production profile above the bed during a 10 minute interval spanning the timeseries in figure 1b. The wave boundary layer extends from approximately 5cm down to the bed, while increasing dissipation rates in the outer boundary layer are associated with the 0.35ms^{-1} mean current at this time.

The laboratory-sized model was adopted to keep the run-time below months on an Origin 2000 workstation. The vertical velocity profile timeseries of middle panel of the figure 1a shows the down-stream signature of strong vertical velocities associated with turbulent eddies shed from the crest of the single cysle ripple spanning the 10 streamwise period model domain. Taking the vertical velocity as representative of turbulent kinetic energy, the modeled energetic eddies were restricted to about 1.5 times the ripple height. Figure 1b shows similar field observations (with differing scales) of velocity structure above the bed morphology shown in figure 2a. The field observations show significantly more structure extending well above the wave boundary layer due to the presence of the significant alongshore current and more complicated bed morphology. The DNS modeling does however provide a valuable method of assessing our ability to measure near-bed dissipation rates based on a Reynolds stress profile and wave–period shear profiles.

Techniques developed to measure and characterize small scale bed morphology during SHOWEX are described in Stanton 2001c. These analysis techniques have allowed the role of forcing factors including mean currents, orbital displacement, wave directional spread, wave groupiness and swell wave asymmetry on the bed formations to be statistically inferred for the SHOWEX duck site. These morphology changes are now being compared with selected timeseries of BBL turbulence to assess morphology contribution to a net friction factor which can be applied to a fine scale regional model.

IMPACT / APPLICATIONS

Observations of cross-shelf wave shoaling and energy loss under low wind conditions across the continental shelf (for example Herbers et al, 2000) suggest that bottom dissipation is a zero'th order term in the cross-shelf wave evolution. Modeling of bottom dissipation in coastal regions will directly improve shelf wave models, which have wide ranging navy and civilian applications.

RELATED PROJECTS

This research has benefited from and contributed to the ONR-sponsored SandyDuck program in the development and deployment of the scanning X/Y altimeter and the prototype BCDV, which address overlapping issues in both programs.

REFERENCES

Anderson, K. H., 1999. The dynamics of ripples beneath surface waves and topics in shell models of turbulence. PhD dissertation, University of Copenhagen.

Arduin, F., T. H. C. Herbers and W. C. O'Reilly, 2000. A hybrid Eulerian-Lagrangian model for spectral evolution with application to bottom friction on the continetal shelf. Accepted for publication in JPO.

Blondeaux, P., Stanton, T. P., Thornton, E. B. and G. Vittori, 1999. Reynolds stress measurements from wave field data. I. A. H. R. Symp. On River, Coastal and Estuarine Morphodynamics, Genova, 6-10 September 1999, Vol II, 11-19.

Blondeaux, P., Stanton, T. P., Thornton, E. B., and G. Vittori, 2000. An approach to measure turbulent stresses in the nearshore region. Submitted to the ICCE2000 conference proceedings.

Stanton, T. P., 1996. Probing ocean wave boundary layers with a hybrid bistatic / monostatic Coherent Acoustic Doppler Profiler. Proceedings of the Microstructure Sensors in the Ocean Workshop, Mt Hood, October 1996.

Stanton, T. P., 1999. The Monterey Inner Shelf Observatory (MISO), web site. http://www.oc.nps.navy.mil/~stanton/miso/

Stanton, T. P., 2001a. High resolution acoustic doppler profiling of velocity, Reynolds stresses and sediment concentration in wave forced boundary layers. Submitted to J. Atmos. and Oceanic Technol.

Stanton, T. P., 2001b. A Turbulence-Resolving Coherent Acosutic Sediment Flux Probe Device and Method For Using. US Patent 6,262,942, issued 17 July 2001.

Stanton, T. P., 2001c. Characterizing wave-forced bedforms using a two axis scanned acoustic altimeter. Submitted to J. Atmos. and Oceanic Technol.

Stanton, T. P. and E, B., Thornton, 2000. Bed form response to wave and current forcing during the Shoaling Waves Experiment, SHOWEX. Submitted to the 6'th International Workshop on Wave Hindcasting and Forecasting.

PUBLICATIONS

Blondeaux, P., Stanton, T. P., Thornton, E. B., and G. Vittori, 2000. An approach to measure turbulent stresses in the nearshore region. Submitted to the ICCE2000 conference proceedings

Stanton, T. P., 2001a. High resolution acoustic doppler profiling of velocity, Reynolds stresses and sediment concentration in wave forced boundary layers. Submitted to J. Atmos. and Oceanic Technol.

Stanton, T. P., 2001c. Characterizing wave-forced bedforms using a two axis scanned acoustic altimeter. Submitted to J. Atmos. and Oceanic Technol.

Websites:

http://www.oc.nps.navy.mil/~stanton/turblab.html

http://www.oc.nps.navy.mil/~stanton/miso/

http://www.oc.nps.navy.mil/~stanton/showex/

PATENT

Stanton, T. P., 2001b. A Turbulence-Resolving Coherent Acoustic Sediment Flux Probe Device and Method For Using. US Patent 6,262,942, issued 17 July 2001.